2002

Ambient noise and signal uncertainties during the summer shelfbreak primer exercise

Abbot, Philip

N. G. Pace and F.B. Jensen (eds.), Impact of Littoral Environmental Variability an Acoustic Predictions and Sonar Performance, 255-262.

AMBIENT NOISE AND SIGNAL UNCERTAINTIES DURING THE SUMMER SHELFBREAK PRIMER EXERCISE

PHILIP ABBOT, CHARLES GEDNEY AND IRA DYER[1]
Ocean Acoustical Services and Instrumentation Systems, Inc.,
5 Militia Drive, Lexington, MA 02421, USA
E-mail: abbot@oasislex.com, gedney@oasislex.com, idyer@aol.com

CHING-SANG CHIU
Naval Postgraduate School, Monterey CA, 93943, USA
E-mail: chiu@nps.navy.mil

Uncertainties in noise level, and in signal level after long-range (42 km) acoustic shallow water transmissions, from a pulsed source, are determined from the summer shelfbreak PRIMER experiment. Fluctuations over the 10-day period are not stationary, but are rendered so by tracking the wandering of their means. Then narrow-sense stationary probability density functions are obtained of ambient noise and signal peak transmissions from a match-filter output with time-bandwidth product = 1. The data are centered at 400 Hz, in a 100 Hz bandwidth, and analyzed from three individual hydrophones of a vertical line array. The ambient noise fluctuations closely follow the phase-random Log-Rayleigh density, with standard deviation σ = 5.6 dB. Signal peak statistics are determined from demeaned 50 s samples. The signal statistics over an 8-h period are approximately similar, but not identical, to those over the entire 10-day period. The signal has narrower histograms ($\sigma \approx$ 0.8 dB) than the noise. Log Chi-Square densities, fit to the signal histograms, suggest that about 30 equal intensity components contribute to the fluctuations, many more than can be attributed to the idealized modal structure in the shelfbreak duct. This suggests that either strong scattering affects the signal transmission, or the signal process is not fully phase-random.

1 Introduction

Realistic sonar performance predictions are served by understanding the causes of temporal and spatial fluctuations in the environment [1–3]. The 1996 summer shelfbreak PRIMER exercise [4–8] provided a high resolution environmental acoustics data set that we use to study the temporal variability of noise and acoustic transmissions. The intent is to evaluate and characterize fluctuations of the ambient noise and signals transmitted over a long range, in a shallow water, downward-refracting environment.

2 Background

The summer Shelfbreak PRIMER experiment was conducted from July 24 to August 2, 1996. The experimental site covered a 60 km square at the shelfbreak of the Middle

[1] Also, MIT Department of Ocean Engineering, Cambridge, MA 02139.

N.G. Pace and F.B. Jensen (eds.), Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance, 255-262.

Atlantic Bight, south of New England, as shown in Fig. 1. The site was selected because of the presence of complex oceanographic phenomena affecting sound propagation across the shelfbreak. These phenomena include the meandering shelfbreak front, and the nonlinear, large-amplitude internal tides and internal solitary waves.

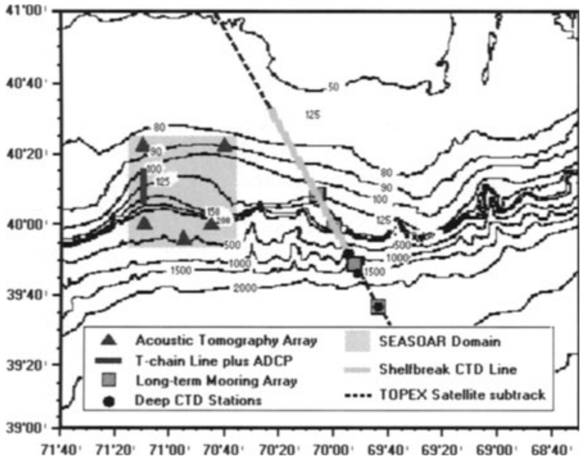

Figure 1. Shelfbreak PRIMER exercise area (triangles show source and receiver locations).

Figure 1 shows the locations of three acoustic sources and two receiver arrays. We consider the propagation along the western edge of the site (from the 400 Hz source at the southwest corner to the array at the northwest corner). The propagation range is 42 km, with water depths of 299 m and 85 m at the source and receiver, respectively. The source was at a depth of 294 m and the receiver array was deployed from 30.5 m to 83 m below the surface (16 hydrophones, 3.5 m spacing). In this paper, we consider signals and noise measured by hydrophones located at depths of 30.5, 55 and 83 m.

The source radiated a 5.11 s pseudo-random binary sequence which provided a pulse compression gain of 27 dB at the output of the matched filter. Pulses were repeated every 5.11 s, over a period of 5 min (resulting in 45–50 pulses per transmission cycle). After each 5 min transmission cycle, the source was shut off for 10 min (while other sources operated). This sequence was repeated for all 10 days of the exercise. The center frequency of the pulse was $f = 400$ Hz, with bandwidth $B = 100$ Hz, at a source level of about 180 dB re 1μPa at 1m. The received signals were processed using a matched filter and the output of this filter is used in the analysis presented here. The τB product of the processed pulses and noise samples is ≈ 1, that is, the temporal resolution $\tau \approx 10$ ms.

3 Analysis and discussion

The matched filter output received at the 30.5 m hydrophone for a typical transmitted pulse is shown in Fig. 2. The peak signal level is about 85 dB re 1μPa and arrives at about 28 s (source to receiver time delay). The signal then decays into the noise, which has peaks of about 70 to 75 dB re 1μPa. For the present analyses, each pulse is divided into two regions: an ambient noise region, with time delays greater than 29 s; and a signal plus noise region, with time delays less than 29 s.

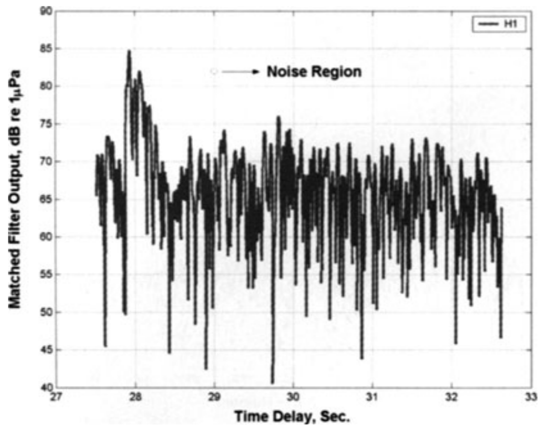

Figure 2. Typical matched filter output time series for a single 5.11-s transmission pulse at the 30.5-m hydrophone. Recorded on 8/1/96.

The mean (μ) and standard deviation (σ) of the matched filter output (in dB) for the ambient noise region is measured for each pulse within a transmission cycle. Figure 3 shows the variations in μ and σ computed in the noise region at the three hydrophones during a typical 5-min transmission cycle. This figure shows that the noise is spatially and temporally wide-sense non-stationary, with varying μ, but σ is relatively constant at about 5.5 dB. This behavior is also observed in the noise data measured at other hydrophones and at other times throughout the exercise. To render the noise narrow-sense stationary, each noise sample was corrected for μ at each hydrophone to give a zero-mean sample set. The resulting histogram, demeaned and aggregated for all 16 hydrophones, over the 5-min transmission cycle (48 pulses) is shown in Fig. 4 (series of dots, normalized to match the PDF). From Dyer [2] we may suppose that, for $\tau B \approx 1$, acoustic ambient noise can be represented as a phase-random process, comprised of one arrival from one distant ship, or another ambient source, resulting in the Log-Rayleigh probability density function (PDF), with standard deviation σ = 5.6 dB. Figure 4 compares the measured histogram with the Log-Rayleigh PDF, and supports the foregoing supposition (with σ = 5.5 dB). Similar results were obtained at all other times (σ = 5.5 to 5.6 dB), and the means wandered. The figure confirms that the phase-random single-component PDF is an excellent representation of the measured noise fluctuations.

The peak output of the matched filter (referred to as the "signal peak") as determined from the signal plus noise region was also recorded for each pulse within a given transmission cycle. Figure 5 shows the signal peak for the shallow hydrophone as measured over an 8-h period on July 24 1996 (0545 to 1345). The noise means are also shown in this figure for comparison. The figure shows the signal and noise at the matched filter output and the corresponding signal fluctuations that are of interest in the present study. In particular, the signal level varies by about 16 dB (from about 80 to 96 dB re 1 µPa) over the 8-h period. It is also interesting to note that the noise mean spreads by about 16 dB as well.

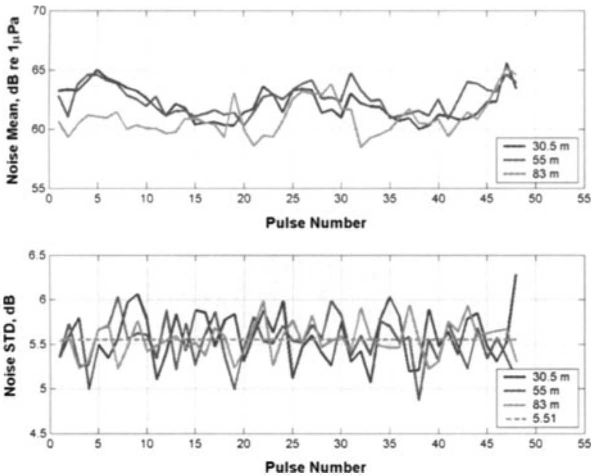

Figure 3. Variation of ambient noise μ and σ for hydrophones located at 30.5, 55 and 83 m depths during a typical 5-min transmission cycle. The time between pulses is 5.11 s. Recorded 8/1/96.

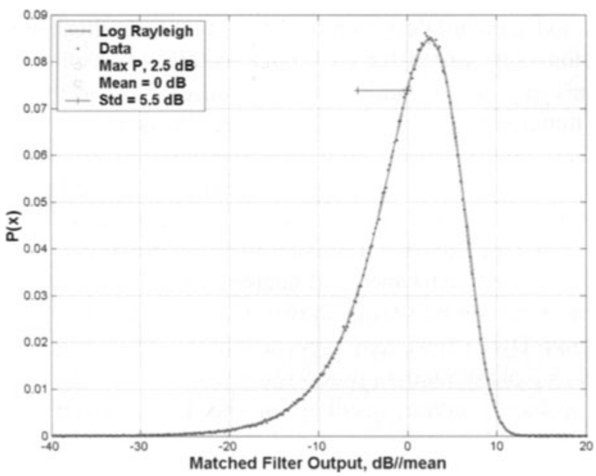

Figure 4. Comparison of the zero-mean noise PDF aggregated in depth over a 5-min transmission series with the single-component phase-random (Log-Rayleigh) PDF. The data points are the normalized height of the histogram level in 0.2 dB bins. Recorded on 8/1/96.

Since there is only one signal peak for each pulse, it is inappropriate to process the signal peaks the same way as for the noise. Rather, we demean the signal peaks every 10 pulses (50 s). We choose N = 10 because it is large enough to show fluctuations in the sample set (and it provides 4 separate groups of 10 samples within a given transmission cycle). Thus for each sample set of 10 pulses (50 s), the μ and σ are determined, the samples demeaned and aggregated, then the process is repeated for the next 10 pulses and so on, for a fixed observation interval (initially set to 8 h). The resulting 8-h histograms over the period as in Fig. 5, and for the three hydrophones, are given in Fig. 6(a)–(c), with the corresponding σ ≈ 0.87, 0.76, and 0.73 dB, respectively starting at the 30.5-m hydrophone. These are much smaller than those for the noise, and decrease slightly with increasing depth. Also shown in the figures are Log Chi-Square fits to the histograms, based on Dyer [2], with the supposition that the signal also is a phase-random process, but with more than one component. For simplicity, these components can be taken as equally intense, and then the fluctuation process would correspond to a number of independent phase-random transmission components, of order 25 to 36 (as shown in the figure). This greatly exceeds that which can be attributed to the idealized modal structure at the receivers in the shelfbreak duct, which suggests that either strong scattering affects the signal transmission, or the process is not fully phase-random. We need to explore these alternatives.

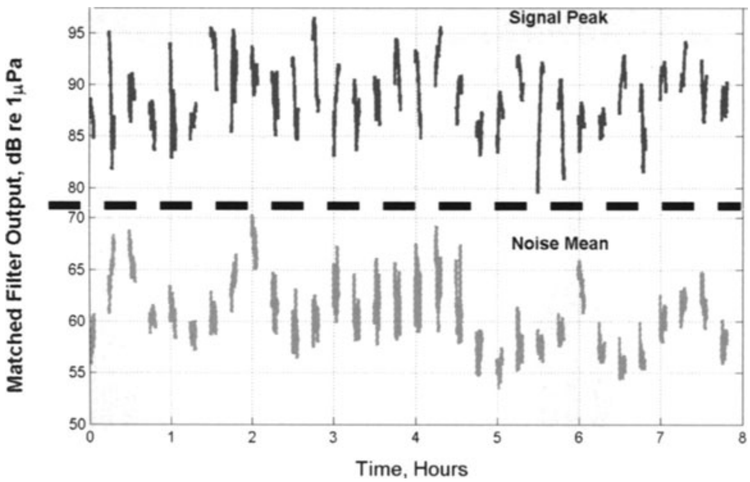

Figure 5. Signal peak output and mean noise level at the 30.5 m hydrophone, versus time for 8-h period, 7/24/96 (0545 to 1345). The blank periods correspond to the 10-min of each 15-min cycle when the source was off (other experiments had different sources transmitting during these times).

A histogram formed over the entire 10-day test (50 s sample size) is shown in Fig. 6d) for the 83 m hydrophone. When compared to the one from the 8-h period on 7/24/96 (Fig. 6c), this histogram is similar in shape, with nearly identical σ. The K-S (Kolmogorov-Smirnov) 2-sample test indicates that the 8-h sample from 7/24/96 has the same PDF (with a 96 % probability) as the 10–day sample. Thus it appears that the fluctuations about the wandering means for an 8-h period adequately represents the fluctuations over the entire 10-day test period, while the means of course vary (see Fig. 8).

As an independent check of this observation, we observed the fluctuations from two other 8-h periods, one during 7/31/96, the other during 7/26/96. On 7/31/96, the signal peak histogram was similar to 7/24/96 (σ = 0.74 dB) with the K-S test indicating a 50% probability that it has the same distribution. Interestingly, the histogram from 7/26/96 was different, with σ = 0.86 dB, and the K-S test indicating a different PDF. Thus, the fluctuations on 7/26/96 were different relative to the 10-day sample set.

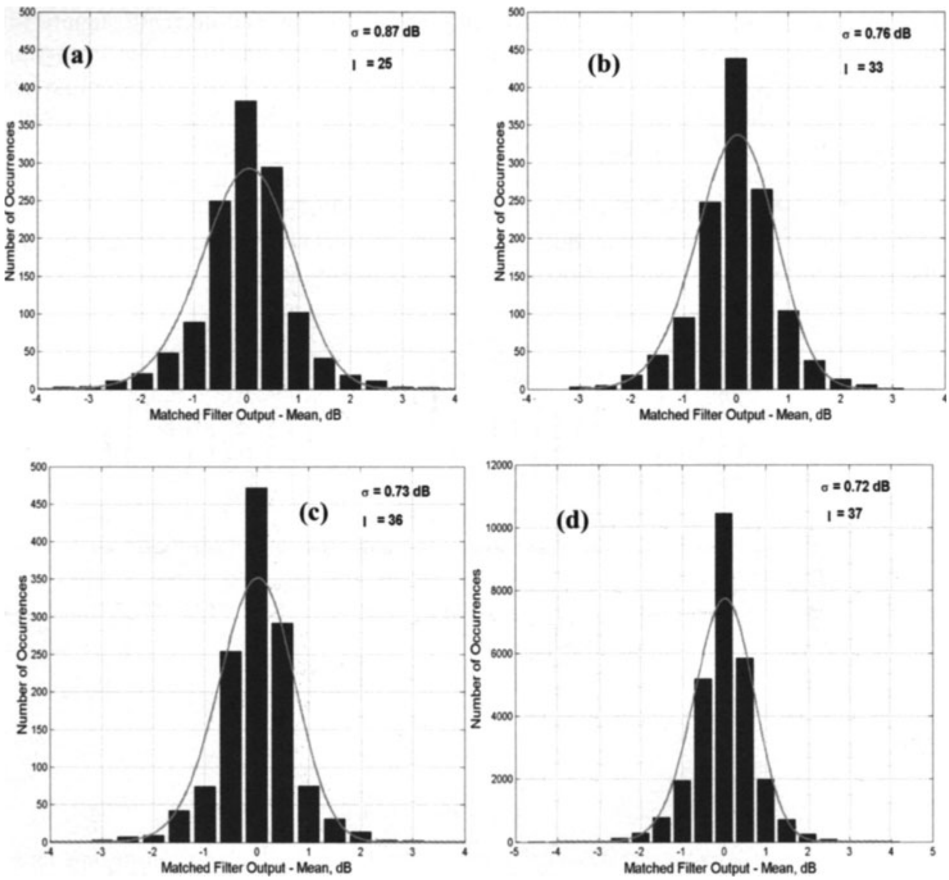

Figure 6. Histograms of demeaned signal peak (50 s sample size) and Log Chi-Square fit (using the l components as shown), during the 8-h period on 7/24/96 for hydrophones located at: a) 30.5 m, b) 55 m, c) 83 m, d) 10-day at 83 m hydrophone .

Figure 7 shows the demeaned σ plotted versus observation interval at the three hydrophones, for intervals of 1, 2, and 8 h, and 1, 2, 5 and 10 days. The figure shows that the σ tends toward a constant level of about 0.8 dB for intervals of 8 h and larger. Below 8 h, the σ are different and dependent on the observation interval, thus suggesting that the fluctuation mechanisms are different for the intervals below and above about 8 h.

In Fig. 8a, the histograms for the slowly wandering mean μ of the noise and signal at the 83 m hydrophone are shown for the 8-h period on 7/24/96. The noise μ varies considerably (with mean M = 59.5 dB re 1 μPa, and standard deviation Σ = 3.0 dB), very much like the noise data in Fig. 3 for a shorter observation time. The signal μ varies as well (M = 91.1 dB re 1 μPa and Σ = 3.1 dB). The wandering means from the 10-day period at the 83 m hydrophone are given in Fig. 8b. Over the 10-day period for the signal, M = 90.0 dB re 1 μPa and Σ = 4.0 dB. These figures show that the signal and noise wandering means have similar characteristics and that the environment is likely affecting both similarly.

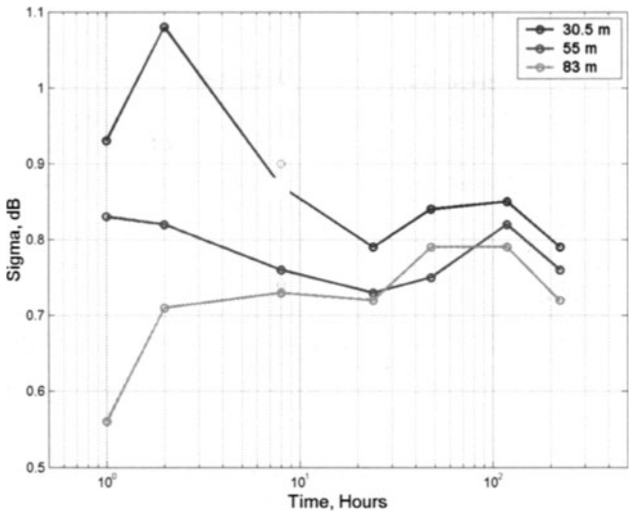

Figure 7. Measured σ versus observation interval (50 s pulse sample size) for hydrophones located at a) 30.5 m, b) 55 m and c) 83 m.

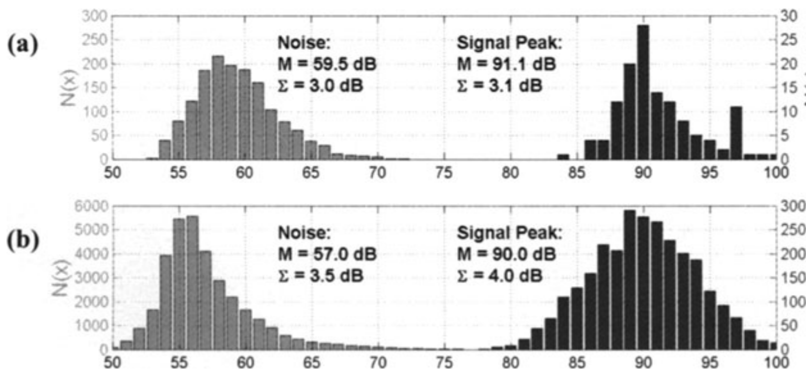

Figure 8. Histograms of noise and signal wandering means at the 83 m hydrophone, a) 8-h, 7/24/96, b) 10-day period.

4 Summary

By demeaning in small time windows, the summer PRIMER ambient noise and signal peak levels were rendered narrow-sense stationary, and the noise and signal histograms about their slowly wandering means were found. The noise fluctuations (about their wandering means) over the 10-day interval are closely phase-random, for they follow a Log-Rayleigh PDF, with $\sigma = 5.6$ dB ($\tau B \approx 1$). The signal peak fluctuations (also about their wandering means) are narrower than the noise with $\sigma \approx 0.8$ dB ($\tau B \approx 1$), for observation intervals of 8 h or larger. Fluctuations over an 8-h period are similar to those over the entire 10-day period, with one exception, suggesting a possible division at 8 h or less in the physical processes underlying the observed fluctuations.

We attempted unsuccessfully to fit signal histograms with an n-component phase-random process model [3] using estimates for the modal amplitudes. The data suggest that there is a significantly larger number of path arrivals contributing to the signals than predicted by the modal analysis. The possibility of micro-pathing in this environment, along with other possibilities, such as incomplete phase-randomness is left to future studies. Also, planned are fluctuation studies for observation intervals smaller than 8 h.

Acknowledgements

This work was sponsored by the Office of Naval Research. We also thank C. Miller (NPS) and C. Emerson (OASIS) for their assistance in processing the PRIMER data set.

References

1. Abbot, P. and Dyer, I., Sonar performance predictions based on environmental variability. In *Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance*, edited by N.G. Pace and F.B. Jensen (Kluwer Academic, The Netherlands, 2002) pp. 611–618.
2. Dyer, I., Statistics of sound propagation in the ocean, *J. Acoust. Soc. Amer.* **48**, 337–345 (1970).
3. Dyer, I., Statistics of distant shipping noise, *J. Acoust. Soc. Amer.* **53**, 564–570 (1973).
4. Lynch, J., Gawarkiewicz, G., Chiu, C., Pickart, R., Miller, J., Smith, K., Robinson, A., Brink, K., Beardsley, R., Sperry, B. and Potty, G., Shelfbreak PRIMER - An integrated acoustic and oceanographic field study in the mid-Atlantic Bight. In *Shallow-Water Acoustics*, edited by R. Zhang and J. Zhou (China Ocean Press, 1997) pp. 205–212.
5. Miller, C., Estimating the acoustic modal arrivals using signals transmitted from two sound sources to a vertical line hydrophone array in the 1996 Shelfbreak PRIMER Experiment. Naval Postgraduate School M.Sc. Thesis, 1998.
6. Colosi, J., Lynch, J., Beardsley, R., Gawarkiewicz, G, Chiu, C. and Scotti, A., Observations of nonlinear internal waves on the New England continental shelf during summer shelfbreak PRIMER, *J. Geophys. Res.* (in press 2002).
7. Chiu, C., Realistic simulation studies of acoustic signal coherence in the presence of an internal soliton wavepacket. In *Proc. IOS/WHOI/ONR Internal Solitary Wave Workshop*, Victoria, B.C., Canada, October 27–29, 1998.
8. Chiu, C., Lynch, J., Gawarkiewicz, G., Miller, C., Sperry, B. and Newhall, A., Measurement and analysis of the propagation of sound from the continental slope to the continental shelf, (in preparation).